

# DIELECTRIC CERAMIC COMPOSITION, ELECTRONIC DEVICE AND THEIR PROCESS OF MANUFACTURING

## BACKGROUND OF THE INVENTION

5

### FIELD OF THE INVENTION

#### 【0001】

The present invention relates to dielectric ceramic composition, electronic device and their process of manufacturing and, further in detail, to  
10 temperature-compensating dielectric ceramic composition of non-reducing property preferably used for electronic device such as multilayer ceramic capacitor having base metal as internal electrode.

### DESCRIPTION OF THE RELATED ART

#### 【0002】

15 Multilayer ceramic capacitor is broadly used as electronic device, and a large number of the multilayer ceramic capacitors is used in an electronic device. Multilayer ceramic capacitor is normally manufactured by stacking the internal electrode layer pastes and dielectric layer pastes with such as sheet method or printing method and thus cofiring.

#### 20 【0003】

Dielectric ceramic material used such as for conventional multilayer ceramic capacitor, when firing in the atmosphere of reducing property, has a property of being reduced and semiconductorized. Therefore, as internal electrode material, metals such as Pd which does not melt at the sintering temperature of dielectric  
25 ceramic material and also does not become oxidized even when firing under high

oxygen pressure which does not semiconductorize the dielectric ceramic material was used.

**【0004】**

However, metals such as Pd are precious that it is a major obstacle for attempt  
5 to reduce the price of multilayer ceramic capacitor. Therefore, as internal electrode material, the use of relatively low priced base metal of Ni or Ni alloys are becoming to be the mainstream.

**【0005】**

On the contrary, when using the base metal as conductive material of internal  
10 electrode layer, firing in an atmosphere leads to the oxidation of the internal electrode. Therefore, dielectric layer and internal electrode layer need to be cofired in reducing atmosphere.

**【0006】**

But when fired in reducing atmosphere, dielectric layer is reduced and  
15 insulation resistance is lowered. Therefore, dielectric material of non-reducing property is provided. For instance, dielectric ceramic compositions of Mg-Ti-O series have excellent temperature characteristic of dielectric constant and widely used for temperature-compensating ceramic capacitor.

**【0007】**

However, these dielectric ceramic compositions of Mg-Ti-O series, when fired  
20 under reducing atmosphere, are reported to be reduced and semiconductorized to have a remarkable property of reducing resistance (See non-patent article 1: Journal of the Ceramic Society of Japan 100 [10] 1992, "Phase-Fine structure change of MgTiO<sub>3</sub> ceramics by treatment in reduction" ). Moreover, dielectric  
25 ceramic compositions of Mg-Ti-O series, for deposit of Ti-rich heterogeneous

phase (Acicular crystal) while sintering, are considered to be difficult for composition control.

**【0008】**

Further, The Patent Article 1: The Japanese Unexamined Patent Publication  
5 No. 11-240753, The Patent Article 2: The Japanese Unexamined Patent  
Publication No. 11-278925 and The Patent Article 3: The Japanese Unexamined  
Patent Publication No. 8-45348 disclose dielectric ceramic composition mainly  
comprising  $\text{MgTiO}_3$ . However, dielectric ceramic compositions as in The Patent  
Articles 1 to 3 were not dielectric ceramic composition of non-reducing property  
10 that can apply to Ni internal electrode.

**【0009】**

The present invention has been made in consideration with the above  
circumstances and has an object to provide dielectric ceramic composition of  
non-reducing property preferably used for multilayer ceramic capacitor having  
15 base metal, such as Ni, as internal electrode which is hard to reduce resistance  
even firing in reduced atmosphere and has high relative dielectric constant and  
small amount of dielectric loss.

**BEST MODE FOR CARRYING OUT THE INVENTION**

**【0010】**

20 The present inventors, to attain the above object, earnestly examined and as a  
result, the followings were detected to complete the present invention. A  
dielectric ceramic composition comprising a main component including 53.00 to  
80.00mol % magnesium oxide converted to  $\text{MgO}$ , 19.60 to 47.00mol % titanium  
oxide converted to  $\text{TiO}_2$  and 0.05 to 0.85 mol % manganese oxide converted to  
25  $\text{MnO}$  is hard to reduce resistance even firing in reduced atmosphere and has

high relative dielectric constant and small amount of dielectric loss.

**【0011】**

That is to say, dielectric ceramic composition according to the present invention comprises a main component including 53.00 to 80.00mol %, preferably 60.00 to  
5 70.00mol %, magnesium oxide converted to MgO, 19.60 to 47.00mol %, preferably 29.60 to 39.90mol %, titanium oxide converted to TiO<sub>2</sub> and 0.05 to 0.85 mol % %, preferably 0.20 to 0.60mol %, manganese oxide converted to MnO.

**【0012】**

When a content of magnesium oxide is too small, on firing in reduced  
10 atmosphere, dielectric ceramic composition is liable to be reduced and semiconductorized, and when too large, it is liable to lower relative dielectric constant.

**【0013】**

When a content of titanium oxide is too small, dielectric ceramic composition is  
15 liable to lower the relative dielectric constant and when too large, it is liable to be reduced and semiconductorized.

**【0014】**

When a content of manganese oxide is too small, dielectric ceramic composition is liable to be reduced and semiconductorized, and when too large, segregation  
20 (segregation such as Mn-Ni-O) with internal electrode material including base metal such as nickel is likely to occur, contact may be defective and reliability is liable to decline.

**【0015】**

Dielectric ceramic composition of the present invention, preferably, as  
25 subcomponent, comprises, with respect to entire dielectric ceramic composition,

0.00 to 0.20 mol%, preferably 0.00 to 0.05 mol% of at least any one of vanadium oxide, yttrium oxide, ytterbium oxide or holmium oxide converted to  $V_2O_5$ ,  $Y_2O_3$ ,  $Yb_2O_3$  and  $Ho_2O_3$  respectively.

**【0016】**

5        These subcomponents, the same as manganese oxide, are materials providing reducing resisting property. When additive amount of these subcomponents are too large, segregation is likely to occur, contact may be defective and reliability is liable to decline.

**【0017】**

10       Manufacturing process of dielectric ceramic composition according to the present invention comprises the steps of preparing source material of said dielectric ceramic composition and firing said source material under the temperature of 1300°C or less, preferably 1150 to 1300°C, more preferably 1250 to 1300°C, to obtain said dielectric ceramic composition.

15       **【0018】**

When firing temperature is too high, rapid grain growth may occur, heterogeneous phase (a Ti-rich phase) is likely to deposit, semiconductorize and reliability is liable to decline.

**【0019】**

20       Preferably, said source material, after fired in reduced atmosphere, is anneal treated (re-oxidizing treatment). With this annealing treatment, insulation resistance improves. Further, reduced atmosphere on firing has oxygen pressure of preferably  $10^{-9}$  to  $10^{-13}$  MPa ( $10^{-8}$  to  $10^{-12}$  atm). Annealing temperature is preferably 1150°C or less and oxygen pressure in the atmosphere is preferably  
25        $10^{-6}$  to  $10^{-9}$  MPa ( $10^{-5}$  to  $10^{-8}$  atm).

**【0020】**

Electronic device according to the present invention comprises dielectric layer wherein said dielectric layer is composed of abovementioned dielectric ceramic composition.

5      **【0021】**

The electronic device of the present invention is preferably an electronic device such as multilayer ceramic capacitor which inner electrode and dielectric layer are stacked alternately.

**【0022】**

10      Present invention is effective when internal electrode at least include base metal such as nickel.

**【0023】**

Manufacturing process of electronic device according to the present invention is characterized in cofiring said internal electrode and dielectric layer under the  
15      temperature of 1300°C or less.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**【0024】**

Below are descriptions of the present invention based on preferred embodiments given with reference to the drawings which

20      FIG. 1 is a cross-sectional view of multilayer ceramic capacitor according to an embodiment of the present invention,

FIG. 2A is a SEM picture of dielectric ceramic composition according to an example of the present invention, and

FIG. 2B is a SEM picture of dielectric ceramic composition according to an  
25      comparative example of the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

【0025】

### Multilayer Ceramic Capacitor

As shown in FIG. 1, a multilayer ceramic capacitor 1 as electronic device  
5 according to an embodiment of the present invention comprises a capacitor  
element body 10 having the configuration wherein dielectric layers 2 and  
internal electrode layers 3 are alternately stacked. At both ends of the capacitor  
element body 10 are formed a pair of external electrode 4 respectively connected  
to the internal electrode layers 3 alternately arranged inside the element body  
10. A shape of the capacitor element body 10 is not particularly limited, but is  
normally made in parallelepiped shape. Further, the capacitor dimensions are  
not limited and may be made with suitable dimensions for the use. Usually,  
however, the dimensions are (0.4 to 5.6 mm) × (0.4 to 5.0 mm) × (0.2 to 1.9  
mm) or so.

15 【0026】

The internal electrode layers 3 are stacked so that the end faces thereof  
alternately protrude out to the surfaces of the two opposing ends of the capacitor  
element body 10. The pair of external electrodes 4 are formed at the two ends of  
the capacitor element body 10 and are connected to the exposed end faces of the  
20 alternately arranged internal electrode layers 3 so as to compose the capacitor  
circuit.

【0027】

### Dielectric Layers 2

The dielectric layers 2 include a dielectric ceramic composition of the present  
25 invention.

Dielectric ceramic composition according to the present invention comprises a main component including 53.00 to 80.00mol %, preferably 60.00 to 70.00mol %, magnesium oxide converted to MgO, 19.60 to 47.00mol %, preferably 29.60 to 39.90mol %, titanium oxide converted to TiO<sub>2</sub> and 0.05 to 0.85 mol %, preferably 0.20 to 0.60mol %, manganese oxide converted to MnO.

**【0028】**

When a content of magnesium oxide is too small, on firing in reduced atmosphere, dielectric ceramic composition is liable to be reduced and semiconductorized, and when too large, it is liable to lower relative dielectric constant.

**【0029】**

When a content of titanium oxide is too small, dielectric ceramic composition is liable to lower the relative dielectric constant and when too large, it is liable to be reduced and semiconductorized.

**【0030】**

When a content of manganese oxide is too small, dielectric ceramic composition is liable to be reduced and semiconductorized, and when too large, segregation (segregation such as Mn·Ni·O) with internal electrode material including base metal such as nickel is likely to occur, contact may be defective and reliability is liable to decline.

**【0031】**

Dielectric ceramic composition of the present invention, preferably, as subcomponent, comprises, with respect to entire dielectric ceramic composition, 0.00 to 0.20 mol%, preferably 0.00 to 0.05 mol% of at least any one of vanadium oxide, yttrium oxide, ytterbium oxide or holmium oxide converted to V<sub>2</sub>O<sub>5</sub>, Y<sub>2</sub>O<sub>3</sub>,



Yb<sub>2</sub>O<sub>3</sub> and Ho<sub>2</sub>O<sub>3</sub> respectively.

**【0032】**

These subcomponents, the same as manganese oxide, are materials providing reducing resisting property. When additive amount of these subcomponents are too large, segregation is likely to occur, contact may be defective and reliability is liable to decline.

**【0033】**

Note that various conditions such as a number of layers or thickness of the dielectric layers 2 as shown in FIG. 1 may be suitably determined with its use and object. Moreover, dielectric layers 2 are composed of crystal grain and particle phase wherein the average particle size of the crystal grain for dielectric layers 2 is preferably 3.0 μm or less. This particle phase normally comprises oxide materials composing dielectric material or internal electrode material, oxide materials separately added or oxide materials mixed as impurity during manufacturing process and are normally composed of glass or holohyaline.

**【0034】**

Internal Electrode Layer 3

A conductive material included in the internal electrode layers 3 is not particularly limited however, for components of the dielectric layers 2 have reducing resisting property, base metals can be used. As the base metal to be used as a conductive material, Ni or Ni alloys are preferable. As the Ni alloys, an alloy of Ni and at least one kind of elements selected from Mn, Cr, Co and Al is preferable and a content of Ni in the alloys are preferably 95 wt% or more. Note that more than 0.1wt% or so of P, Fe, Mg and other various trace constituents may be included in the Ni or Ni alloys.

A thickness of the internal electrode layers may be suitably determined in accordance with use, etc. but is normally 0.5 to 5  $\mu$  m, particularly 1 to 2.5  $\mu$  m or so is preferable.

【0035】

5     External Electrode 4

A conductive material included in the external electrode 4 is not particularly limited, but normally Cu, Ni or alloys of these are used. Further, such as Ag or Ag-Pd alloys can be used as a matter of course. Moreover, according to the preferred embodiments of the invention, inexpensive Ni, Cu or alloys of these  
10    are used. A thickness of the external electrode may be suitably determined in accordance with use, etc. but normally 10 to 50  $\mu$  m or so is preferable.

【0036】

Manufacturing Process of Multilayer Ceramic Capacitor

A multilayer ceramic capacitor using dielectric ceramic composition of the  
15    present invention, in the same way as manufacturing conventional multilayer ceramic capacitor, is manufactured by preparing a green chip by a normal printing method or a sheet method using a paste, firing the same, printing or transferring an external electrode. Following is the manufacturing process concretely described.

20     【0037】

First, dielectric layer paste, internal electrode paste and external electrode paste are respectively manufactured.

【0038】

Dielectric Layer Paste

25     The dielectric layer paste may be an organic-based paint comprising a

mixture of a dielectric source material and an organic vehicle and may also be water-based paint.

**【0039】**

As dielectric source material, according to the composition for said dielectric ceramic composition of the present invention, a source material composing main component and subcomponent is used. Further, source material configuration is not particularly limited and oxides compose main component and subcomponent and/or compounds becoming oxides by firing are used. Those source materials may also be powdered obtained by such as liquid-phase synthesis or solid-phase method.

**【0040】**

Further, as compounds becoming oxides by firing, carbonates, nitrates, oxalates and organic metal compounds are exemplified. The oxides and the compounds becoming oxides by firing can both be used of course. The content of each compound in the dielectric source material may be suitably determined so as to give the above composition of the dielectric ceramic composition after firing. These source material powder, according to the preferred embodiment of the invention, having average particle size of 0.0005 to 2.0  $\mu$  m or so is used.

**【0041】**

The organic vehicle comprises a binder dissolved in an organic solvent. The binder used for the organic vehicle is not particularly limited, but may be suitably selected from ethyl cellulose, polyvinyl butyral, and other ordinary types of binders. Further, the organic solvent used is also not particularly limited and may be suitably selected from terpeneol, butyl carbitol, acetone, toluene, and other organic solvents, etc. in accordance with the printing method,

sheet method, or other method of use.

**【0042】**

Further, a water-based paint comprises a water-based binder, dispersant, etc. dissolved in water. The water-based binder is not particularly limited, but may  
5 be suitably selected from polyvinyl alcohol, cellulose, water-based acrylic resin, emulsion, etc.

**【0043】**

According to the preferred embodiment of the invention, after weighing the abovementioned dielectric source material powder, pouring water as medium,  
10 mixing for 10 to 40 hours or so, drying the mixture and calcinating the mixture preferably at 1100 to 1300°C for 2 to 4 hours. Afterwards, the calcinated material is subjected to wet grinding by using a ball mill and mixing with abovementioned vehicle to balance paste to be dielectric paste.

**【0044】**

Internal Electrode Paste, External Electrode Paste

The internal electrode paste is prepared by kneading the electroconductive material comprising the above various types of electroconductive metals and alloys or various types of oxides becoming the above electroconductive materials after firing, an organic metal compound, resinate, etc. together with the above  
20 organic vehicle.

The external electrode paste is prepared in the same way as in the above internal electrode paste.

**【0045】**

The content of the organic vehicle in the above each paste is not particularly  
25 limited and may fall within the usual amount, for example, the binder may be

contained in the amount of 1 to 5wt% or so and solvent 10 to 50wt% or so. Further, the each paste may include, in accordance with need, various types of additives selected from dispersants, plasticizers, dielectrics, insulators, etc.

#### **【0046】**

5 When using a printing method, the dielectric paste and the internal electrode paste are successively printed on the polyethylene terephthalate or other substrate, then cut into a predetermined shape, afterwhich the pastes are peeled off from the substrate to form a green chip. To the contrary, when using a sheet method, a dielectric paste is used to form a green sheet, the internal  
10 electrode paste is printed on upper surface of this, after which these are stacked to form a green chip.

#### **【0047】**

Next, this green chip is processed to remove the binder and to fire.

#### **【0048】**

#### **15 Removing Binder Treatment**

The removing binder treatment can be performed under general condition, but particularly when using Ni or Ni alloys or other base metals as the electroconductive material for internal electrode layers, it is determined that in air atmosphere, temperature raising rate is 5 to 300°C/hour, in particular 10 to  
20 100°C/hour, a holding temperature is 180 to 400°C, in particular 200 to 300°C, and a temperature holding time is 5 to 24 hours, in particular 5 to 20 hours.

#### **【0049】**

#### **Firing (Sintering)**

Firing atmosphere for the green chip may be suitably determined in  
25 accordance with the type of electroconductive material in the internal electrode

layer paste, but when using Ni or Ni alloys or other base metal as the electroconductive material, it is preferable to reduce atmosphere and oxygen partial pressure in the firing atmosphere is preferably  $10^{-9}$  to  $10^{-16}$  MPa ( $10^{-8}$  to  $10^{-15}$  atm), more preferably,  $10^{-9}$  to  $10^{-13}$  MPa ( $10^{-8}$  to  $10^{-12}$  atm). When oxygen partial pressure at firing is too low, the electroconductive material of this internal electrode tend to become abnormally sintered and broken in the middle. While when oxygen partial pressure at the firing is too high, the internal electrode tend to become oxidized.

【0050】

The holding temperature at firing is  $1300^{\circ}\text{C}$  or less, preferably  $1000$  to  $1300^{\circ}\text{C}$ , more preferably  $1200$  to  $1300^{\circ}\text{C}$ . When the holding temperature is too low, the densification tend to become insufficient, while when the holding temperature is too high, there is a tendency toward breaking of the electrodes due to abnormal sintering in the internal electrode, or deterioration of the temperature dependence of capacitance due to dispersion of the internal electrode material.

【0051】

The firing conditions other than the above conditions are that preferably, the temperature raising rate is  $50$  to  $500^{\circ}\text{C}/\text{hour}$ , more preferably,  $200$  to  $300^{\circ}\text{C}/\text{hour}$ , a temperature holding time is  $0.5$  to  $8$  hours, more preferably,  $1$  to  $3$  hours, and the cooling rate is  $50$  to  $500^{\circ}\text{C}/\text{hour}$ , more preferably,  $200$  to  $300^{\circ}\text{C}/\text{hour}$ . The firing atmosphere is desirable to be reducing atmosphere and as the atmosphere gas, it is preferable to use, for instance, a wet mixed gas of nitrogen gas and hydrogen gas.

【0052】

After firing in the reducing atmosphere, the fired body of capacitor tip is

preferably anneal treated(heat treatment).

【0053】

Annealing (Heat Treatment)

The annealing is a treatment that re-oxidizes dielectric layer and this, enables  
5 the insulation resistance to increase. In annealing atmosphere, the oxygen  
partial pressure is preferably  $10^{-10}$  MPa ( $10^{-9}$  atm) or more, more preferably,  $10^{-6}$   
to  $10^{-9}$  MPa ( $10^{-5}$  to  $10^{-8}$  atm). When oxygen partial pressure is too low,  
re-oxidation of the dielectric layers 2 is difficult, while when oxygen partial  
pressure is too high, the internal electrode layers 3 tend to become oxidized.

10 【0054】

The holding temperature at the time of annealing is 1150°C or less, more  
preferably 500 to 1100°C. When the holding temperature is too low, re-oxidation  
of the dielectric layers become insufficient so the insulation resistance tends to  
deteriorate and its accelerating lifetime short. On the other hand, when the  
15 holding temperature is too high, not only do the internal electrode oxidize and  
the capacitance fall, but also end up reacting with the dielectric component  
resulting in a tendency toward deterioration of the temperature dependence of  
capacitance, the insulation resistance and its accelerating lifetime. Note that  
the annealing may be composed of only a temperature raising process and a  
20 temperature reducing process. In this case, the temperature holding time is zero  
and the holding temperature is synonymous with the maximum temperature.

【0055】

The conditions other than the above conditions in annealing are that the  
temperature holding time is 0 to 20 hours, more preferably, 6 to 10 hours, the  
25 cooling rate is 50 to 500°C/hour, more preferably, 100 to 300°C/hour. Note that

for annealing atmospheric gas, preferably a wet nitrogen gas is used

**【0056】**

Further, in the same way as abovementioned firing, during the process for said removing binder treatment and annealing process, to wet nitrogen gas or  
5 mixed gas, a wetter, etc. may be used. In this case, the temperature of the water is preferably 5 to 75°C.

**【0057】**

Moreover, the removing binder treatment, firing, and annealing may be performed consecutively or independently. When these processes are performed  
10 consecutively, it is preferable to proceed with following order. Treating to remove binder, changing the atmosphere without cooling, followed by raising the temperature to holding temperature of firing, cooling to the holding temperature of annealing, and anneal treating by changing atmosphere. To the contrary, when these processes are performed independently, for firing, after  
15 raising the temperature to holding temperature of removing binder treatment in the atmosphere of nitrogen gas or wet nitrogen gas, further raising of the temperature in the changed atmosphere is preferable. And after cooling to the holding temperature of annealing, changing the atmosphere again to the nitrogen gas or wet nitrogen gas, continued cooling is preferable. Also,  
20 considering the annealing, after raising the temperature of holding temperature in nitrogen gas atmosphere, the atmosphere can be changed or whole annealing process can be proceeded in wet nitrogen gas atmosphere.

**【0058】**

The thus obtained capacitor fired body is, for instance, end polished using  
25 barrel polishing or sandblasting etc., then printed or transferred with an



external electrode paste and fired to form the external electrodes 4. The firing conditions of the external electrode paste are, for instance, preferably 600 to 800°C for 10 minutes to 1 hour or so in a wet mixed gas of nitrogen or hydrogen. Further, in accordance with need, the surfaces of the external electrodes 4 may  
5 be formed with a covering layer(pad layer) using plating techniques, etc.

#### 【0059】

The thus produced ceramic capacitor 1 of the preferred embodiment of the invention is mounted onto a printed substrate by soldering, etc. for use in various types electronic equipment.

#### 10 【0060】

Note that present invention is not limited to the abovementioned embodiments and may be modified in various ways within the scope of the invention.

#### 【0061】

15 For instance, in the abovementioned embodiments, illustration was made of a multilayer ceramic capacitor as the electronic device according to the present invention, but the electronic device according to the present invention is not limited to a multilayer ceramic capacitor and may be any device having dielectric layer composed of a dielectric ceramic composition of the above  
20 composition.

#### 【0062】

#### Examples

Below are concrete examples for the preferred embodiment of the present invention describing the invention further in detail. However, the present  
25 invention is not limited by the examples.

【0063】

Example 1

First, as starting source material of manufacturing dielectric material, a main component materials (MgO, TiO<sub>2</sub>, MnCO<sub>3</sub>), and subcomponent materials (V<sub>2</sub>O<sub>5</sub>,  
5 Y<sub>2</sub>O<sub>3</sub>, Yb<sub>2</sub>O<sub>3</sub>, Ho<sub>2</sub>O<sub>3</sub>) respectively having an average particle size of 0.1 to 1.0  $\mu$  m were prepared.

【0064】

After these source materials were weighed in order that the compositions after firing become as shown in belowmentioned table 1, to these source  
10 materials, water as medium was poured and mixed for 16 hours by ball mill. Then, the mixture was dried and the dried material was calcinated at 1200°C for 2 hours. Afterwards, the obtained calcinated material was subjected to wet grinding by ball mill and was dried.

【0065】

15 100 parts by weight of thus obtained dried dielectric source material, 5.4 parts by weight of acrylic resin, 16 parts by weight of MEK(Methyl Ether Ketone), 45 parts by weight of acetone, 6 parts by weight of mineral spirits and 4 parts by weight of toluene were mixed by ball mill to make a paste and dielectric paste was obtained.

20 【0066】

Then, 100 parts by weight having Ni particles of an average particle size of 0.8  $\mu$  m, 35 parts by weight of organic vehicle (8 parts by weight of an ethyl cellulose dissolved in 92 parts by weight of butyl carbitol) and 7 parts by weight of butyl carbntitol were kneaded to make a paste and internal electrode layer  
25 paste was obtained.

【0067】

Then, 100 parts by weight of Cu particles of an average particle size of  $0.5\ \mu\text{m}$ , 35 parts by weight of organic vehicle, (8 parts by weight of an ethyl cellulose dissolved in 92 parts by weight of butyl carbitol) and 7 parts by weight of butyl carbinitol were kneaded by a triple-roll to make pastes and external electrode pastes were obtained.

【0068】

First, the abovementioned dielectric layer paste was used to form green sheet having  $25\ \mu\text{m}$  thickness on a PET film. The internal electrode layer paste was printed on this, then the sheet was peeled off from the PET film. Second, the thus obtained green sheets and protection green sheet (on which the internal electrode layer paste is not printed) were layered, adhered by means of pressure to prepare a green chip. The number of layered sheets comprising the internal electrode was 4.

【0069】

Then the green chip was cut to a predetermined size and was processed to remove the binder, fire and anneal(heat treatment) and obtained a multilayer ceramic fired body. The removing binder treatment was performed under conditions of a temperature raising rate of  $15^{\circ}\text{C}/\text{hour}$ , a holding temperature of  $280^{\circ}\text{C}$ , a temperature holding time is 8 hours, and in the air atmosphere. And firing conditions were a temperature raising rate of  $200^{\circ}\text{C}/\text{hour}$ , a holding temperature of  $1300^{\circ}\text{C}$ , a temperature holding time of 2 hours, a cooling rate of  $300^{\circ}\text{C}/\text{hour}$  and in an atmosphere of a wet mixed gas of  $\text{N}_2 + \text{H}_2$  (oxygen partial pressure was  $10^{-9}$  to  $10^{-13}\text{MPa}$  ( $10^{-8}$  to  $10^{-12}\text{atm}$ )). The annealing conditions were a holding temperature of  $1100^{\circ}\text{C}$ , a temperature holding time of 3 hours, a

cooling rate of 300°C/hour, and in an atmosphere of a wet N<sub>2</sub> gas (oxygen partial pressure was 10<sup>-6</sup> MPa (10<sup>-5</sup> atm). Note that at the time of firing and annealing, for wetting the atmosphere gasses, a wetter having a water temperature of 35°C was used.

5        **【0070】**

Then after the end faces of the multilayer ceramic fired body were polished by sandblasting, external electrode paste was transferred to the end faces and in an atmosphere of wet gasses of N<sub>2</sub> + H<sub>2</sub>, fired at 800°C for 10 minutes to form external electrode so as to obtain samples of a multilayer ceramic capacitor as  
10 composition shown in FIG. 1.

**【0071】**

The size of the thus obtained capacitor samples was 3.2mm × 1.6mm × 0.6mm, the number of dielectric layers sandwiched by the internal electrode layers was 4 and their thickness was 15 μm, and the thickness of the internal  
15 electrode layers was 2 μm. The characteristics below of the respective samples were evaluated.

**【0072】**

Relative Electric Constant(ε<sub>r</sub>) , Dielectric Loss Tangent(tan δ),

Insulation Resistance(IR)

20        The capacitance of the sample capacitors were measured at standard temperature of 25 °C by a digital LCR meter(4274A, YHP made) under conditions of a frequency 1kHz, and an input signal level(a measurement voltage) of 1Vrms. Then, by thus obtained capacitance and electrode dimension and interelectrode distance for the sample capacitors, relative dielectric  
25 constant(no unit) were calculated.

**【0073】**

Further, the dielectric loss tangent(unit in %) of the capacitor sample were measured by the LCR meter used when calculating the relative dielectric constant, under conditions of 25°C and 1kHz.

5 **【0074】**

Insulation resistance(unit in  $\Omega$ ) was measured by the insulation tasting set(R8340A, Advantest made), under conditions of 25°C and DC50V. The result is shown in Table 1.

Table 1

	Compositions [mol%]			Additives [mol%]			Electro-Characteristics			
	MgO	TiO2	MnO	V2O5	Y2O3	Yb2O3	Ho2O3	$\epsilon$ s	$\tan \delta$ [%]	IR[ $\Omega$ ]
※1	49.79	49.79	0.42	0.00	0.00	0.00	0.00	27	3.51	incapable
※2	50.00	50.00	0.00	0.00	0.00	0.00	0.00	32	6.04	incapable
※3	66.67	33.33	0.00	0.00	0.00	0.00	0.00	21	0.10	incapable
4	66.62	33.31	0.08	0.00	0.00	0.00	0.00	17	0.08	5*10 <sup>10</sup>
5	66.52	33.26	0.23	0.00	0.00	0.00	0.00	17	0.07	6*10 <sup>10</sup>
6	66.42	33.21	0.38	0.00	0.00	0.00	0.00	19	0.05	3*10 <sup>10</sup>
7	66.27	33.13	0.60	0.00	0.00	0.00	0.00	19	0.05	7*10 <sup>10</sup>
8	66.17	33.08	0.75	0.00	0.00	0.00	0.00	20	0.05	8*10 <sup>10</sup>
9	66.13	33.06	0.81	0.00	0.00	0.00	0.00	19	0.05	8*10 <sup>10</sup>
※10	66.09	33.05	0.86	0.00	0.00	0.00	0.00	6	1.50	3*10 <sup>13</sup>
※11	52.16	47.42	0.42	0.00	0.00	0.00	0.00	26	3.08	3*10 <sup>7</sup>
12	54.32	45.27	0.41	0.00	0.00	0.00	0.00	20	0.09	5*10 <sup>10</sup>
13	79.73	19.93	0.34	0.00	0.00	0.00	0.00	14	0.04	7*10 <sup>10</sup>
※14	80.12	19.54	0.34	0.00	0.00	0.00	0.00	8	0.05	9*10 <sup>10</sup>
15	66.42	33.21	0.28	0.10	0.00	0.00	0.00	19	0.05	3*10 <sup>10</sup>
16	66.42	33.21	0.18	0.20	0.00	0.00	0.00	18	0.05	1*10 <sup>10</sup>
※17	66.42	33.21	0.13	0.25	0.00	0.00	0.00	16	0.09	1*10 <sup>10</sup>
18	66.42	33.21	0.28	0.00	0.10	0.00	0.00	19	0.05	1*10 <sup>10</sup>
19	66.42	33.21	0.28	0.00	0.00	0.10	0.00	19	0.05	5*10 <sup>10</sup>
20	66.42	33.21	0.28	0.05	0.05	0.00	0.00	19	0.05	2*10 <sup>10</sup>
21	66.42	33.21	0.28	0.00	0.05	0.05	0.00	19	0.05	2*10 <sup>10</sup>
22	66.42	33.21	0.28	0.03	0.03	0.03	0.00	19	0.05	2*10 <sup>10</sup>
23	66.42	33.21	0.18	0.20	0.00	0.00	0.10	19	0.05	4*10 <sup>10</sup>
24	66.42	33.21	0.28	0.03	0.00	0.00	0.00	20	0.04	3*10 <sup>11</sup>
25	66.42	33.21	0.28	0.00	0.03	0.00	0.00	20	0.04	3*10 <sup>11</sup>
26	66.42	33.21	0.28	0.00	0.00	0.03	0.00	20	0.04	3*10 <sup>11</sup>
27	66.42	33.21	0.28	0.00	0.00	0.00	0.03	20	0.04	3*10 <sup>11</sup>

※Compositions out of the range

5       【0076】

Further, according to table 1, figures with the symbol “\*” of the sample numbers are the sample numbers having composition out of preferable composition range for the present invention. It is the same with the other tables.

5       【0077】

Evaluation 1

As shown in table 1, by comparing the sample numbers 1 to 14, dielectric ceramic composition comprising 53.00 to 80.00mol %, preferably 60.00 to 70.00mol %, magnesium oxide converted to MgO, 19.60 to 47.00mol %, preferably 29.60 to 39.90mol %, titanium oxide converted to TiO<sub>2</sub> and 0.05 to 0.85 mol %, preferably 0.20 to 0.60mol %, manganese oxide converted to MnO was preferable. That is, when these compositions were used, even when fired in reduced atmosphere, it was difficult to lower the resistance and relative dielectric constant were high, further, dielectric loss tangent were less.

15      【0078】

Further, by comparing the sample numbers 15 to 23, dielectric ceramic composition according to the present invention, preferably, as subcomponent, with respect to entire dielectric ceramic composition, comprises 0.00 to 0.20 mol% of at least any one of vanadium oxide, yttrium oxide, ytterbium oxide or holmium oxide converted to V<sub>2</sub>O<sub>5</sub>, Y<sub>2</sub>O<sub>3</sub>, Yb<sub>2</sub>O<sub>3</sub> and Ho<sub>2</sub>O<sub>3</sub> respectively. That is, when these subcomponents were comprised at a determined mol%, even when fired in reduced atmosphere, it was difficult to lower the resistance and relative dielectric constant were high, further, dielectric loss tangent were less.

Furthermore, by comparing the sample numbers 24 to 27 and sample number 15, the abovementioned 0.00 to 0.20 mol% was more preferable in 0.00 to 0.05

mol%.

【0079】

Example 2

Capacitor samples were prepared in the same way as the sample number 6 in example 1 except firing was proceeded at 1250°C or 1350°C. And in the same way as example 1, insulation resistance was tested. Further, in example 2, high temperature loading test was performed and the fraction defective was measured. Also, SEM picture for cross-sectional view of dielectric layer in capacitor samples was observed to see if the heterogeneous phase (a Ti-rich phase) exists. The result is shown in Table 2.

【0080】

Table 2

	Firing Temperature (°C)	Heterogeneous Phase (Ti-rich phase)	Electro-Characteristic IR[Ω]	High Temperature Loading Test Fraction Defective[%]
15 24	1250	not existed	$2 \times 10^{10}$	0.0
6	1300	not existed	$3 \times 10^{10}$	0.0
※25	1350	existed	incapable	100.0

【0081】

At high temperature loading test, 20 capacitor samples prepared under the same condition were impressed with DC 100V at 150°C and after left for 1000 hours, insulation resistances(IR) were measured. For each 20 capacitor samples, insulation resistances(IR) under  $1 \times 10^8 \Omega$  were considered as defective goods and the defective ratios for those were calculated.

【0082】

Further, SEM picture for cross-sectional view of dielectric layer in sample



number 6 is shown in FIG. 2A and SEM picture for cross-sectional view of dielectric layer in sample number 26 is shown in FIG. 2A. The existence of the heterogeneous phase is considered by the existence of the heterogeneous phase in FIG. 2B.

5       【0083】

Evaluation 2

As shown in table 2, by comparing sample numbers 6, 24, and 25, firing temperature was preferable at 1300°C or less and 1250°C was also possible to be sintered. Also, as the result shown in table 2, when heterogeneous phase  
10       existed, dielectric layer semiconductorized and the reliability declined.

      【0084】

Example 3

Capacitor samples were prepared in the same way as the sample number 6 in example 1 except annealing treatment was not proceeded. And in the same way  
15       as example 1, insulation resistance was tested. The result is shown in Table 3.

      【0085】

Table 3

	Annealing (N2 only)	Electro-Characteristic IR[Ω]
26	not treated	$4 \times 10^9$
20   6	treated	$3 \times 10^{10}$

      【0086】

Evaluation 3

As shown in table 3, by comparing sample number 26 and sample number 6,  
25       with this annealing treatment, insulation resistance improved.

**【0087】**

According to the description above, the present invention is able to provide dielectric ceramic composition of non-reducing property preferably used for multilayer ceramic capacitor having base metal, such as Ni, as internal  
5 electrode which is hard to reduce resistance even firing in reduced atmosphere, and has high relative dielectric constant and small amount of dielectric loss.